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CHARACTERISTICS AND SAMPLING EFFICIENCY OF EIGHT-UNIT LINEAR SLOT IMPACTOR (EULSI)

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14. ABSTRACT
The aerosol sampling efficiency was determined for an Eight-Unit Linear Slot Impactor (EULSI) developed at the Texas A&M University (College Station, TX). EULSI is a virtual impactor that has one concentration stage consisting of eight parallel linear accelerating and eight matching receiving jets. Sampling efficiency was determined using 1- and 3-μm fluorescent polystyrene latex (PSL) microspheres; 5-, 7-, 9-, and 12-μm fluorescent oleic acid particles; and dry *Bacillus subtilis var. niger* [*Bacillus globigii* (Bg)]. The results show a broad maximum sampling efficiency response of 35-37% between 3 and 7 μm. The efficiency drops off slightly at 9 and 12 μm, but only to 32 and 28%, respectively. The 1-μm PSL and Bg particles yielded a sampling efficiency of 21% ± 3 and 17% ± 12, respectively. The standard deviation for the measured sampling efficiency of the Bg particles was higher (± 12) compared to the standard deviation of the non-biological particles due to culturing variability.

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PREFACE

The work described in this report was authorized under Project No. 206023.84BPO, Non-Medical CB Defense. The work was started in March 2004 and completed in May 2004.

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CHARACTERISTICS AND SAMPLING EFFICIENCY OF EIGHT-UNIT LINEAR SLOT IMPACTOR (EULSI)

1. INTRODUCTION

This technical note is one in a continuing series of short reports intended to document and preserve the record of data from characterizing aerosol collectors. This report is not intended to be a comprehensive study or analysis. A technical note simply records a limited set of observations, offers some preliminary analysis, and if appropriate, provides a record of the measured data to the group that provided the device. Results of more thorough studies may be found in technical reports.

In this study, an Eight-Unit Linear Slot Impactor (EULSI) developed by the Texas A&M University (College Station, TX) was characterized at the U.S. Army Edgewood Chemical Biological Center (ECBC) using fluorescent polystyrene latex (PSL) microspheres, fluorescent oleic acid particles, and dry *Bacillus subtilis var. niger* [*Bacillus globigii* (Bg)]. The analysis of the PSL beads and the oleic acid particles was by fluorometry. The Bg testing was based on a culture analysis. The tests were conducted to determine the sampling efficiency at calm air conditions, and do not include inlet efficiencies at varying wind velocities.

The sampling efficiency is defined as the efficiency with which an aerosol sampler collects particles from the air. The total efficiency of an aerosol sampler is the product of the sampler's aspiration, transmission, and collection efficiencies. The aspiration efficiency of a sampler gives the efficiency with which particles enter into the sampler inlet. Transmission efficiency gives the efficiency with which the particles are transported to the collection point, and the collection efficiency gives the efficiency with which particles are captured and retained by the sampling medium. The sampling efficiency was determined by comparing the sample collected by the EULSI to reference samples collected by two stationary open-face air filters. In addition, characteristics such as dimensions, air flowrate, and power consumption were measured.

2. EQUIPMENT AND FACILITIES

2.1 Chamber.

The tests were conducted in a 70-m^3 biosafety Level 1+ chamber (Figure 1) at ECBC. Chamber temperature and humidity can be set and easily and accurately maintained by a computer. This computer also controls power receptacles inside the chamber.

To achieve very low particle concentrations in the chamber, HEPA filters are installed at the air inlet to filter air entering the chamber. Similarly, HEPA filters are installed at the exhaust port to filter particles leaving the chamber. The aerosol concentration in the chamber is reduced by exhausting chamber air through the HEPA filters, and by pumping HEPA-filtered air into the chamber. The maximum amount of airflow that the exhaust pump can exhaust from

the chamber is approximately 700 ft^3/min (approximately 2 x 10^4 L/min). There is also a small re-circulation system that removes air from the chamber, passes it through a HEPA filter, and delivers it back to the chamber. This system is useful when the aerosol concentration in the chamber needs to be reduced by a small amount.

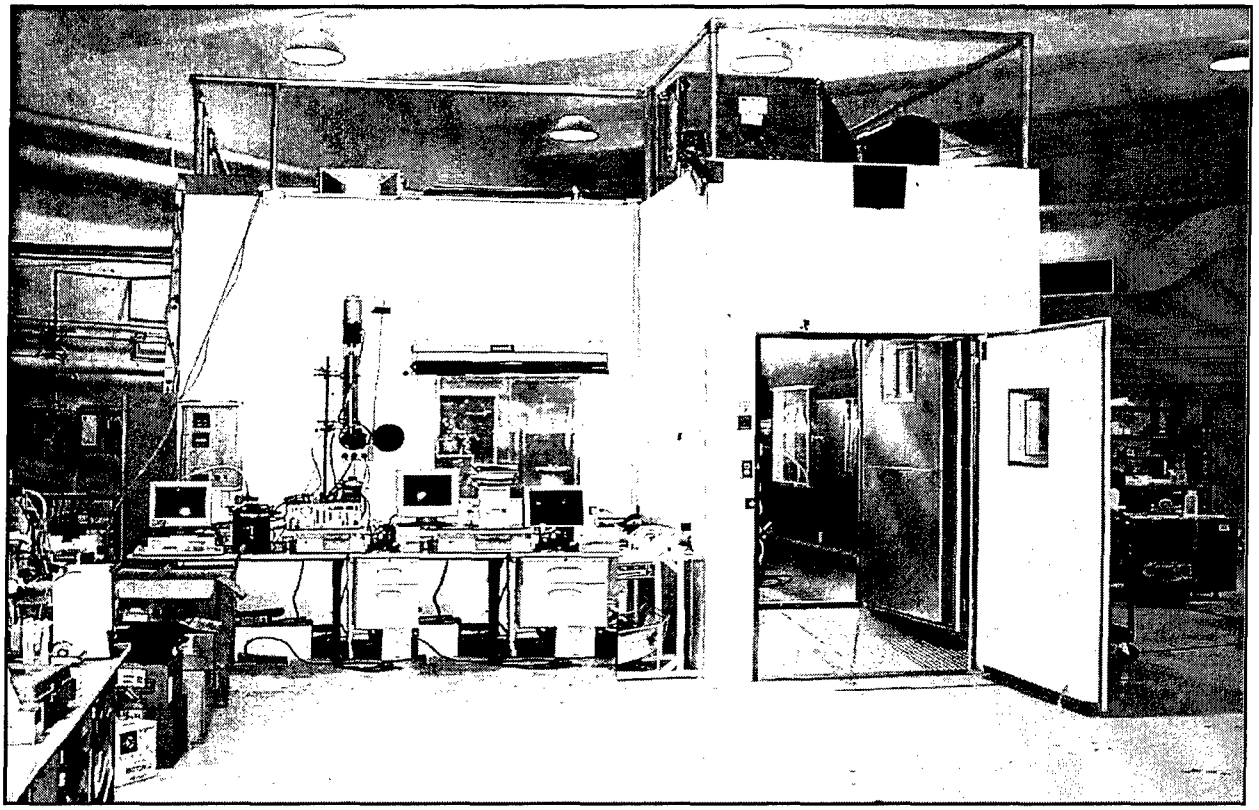

Figure 1. 70-m^3 Aerosol Chamber at ECBC

Aerosols can either be generated outside and delivered to the chamber, or they can be generated inside the chamber. A fan mixes the chamber air before and/or during the experiment to achieve uniform aerosol concentration in the chamber. Previous tests show that mixing the aerosol in the chamber for 1 min is adequate to achieve uniform aerosol concentration.

2.2 Characteristics of the EULSI.

The EULSI is a one-stage virtual impactor (Figure 2). It has eight linear slots to accelerate the air and eight matching receiving slots to capture the particles. Each accelerating slot is 0.012 in. by 5 in., and the receiving slot is 0.018 in. by 5 in. in size. Figure 3 shows an individual slot. The EULSI was designed with a total inlet flowrate of 270 L/min. However, the measured inlet air flowrate at ECBC with the manufacturer's settings was 367.1 L/min for the

PSL tests and 370.2 L/min for the fluorescent oleic acid tests. The minor air flowrate was 27.2 L/min with a glass fiber filter and 24.1 L/min with a membrane filter.

Figures 2 and 3 show pictures of the EULSI, and its characteristics are summarized in Table 1.

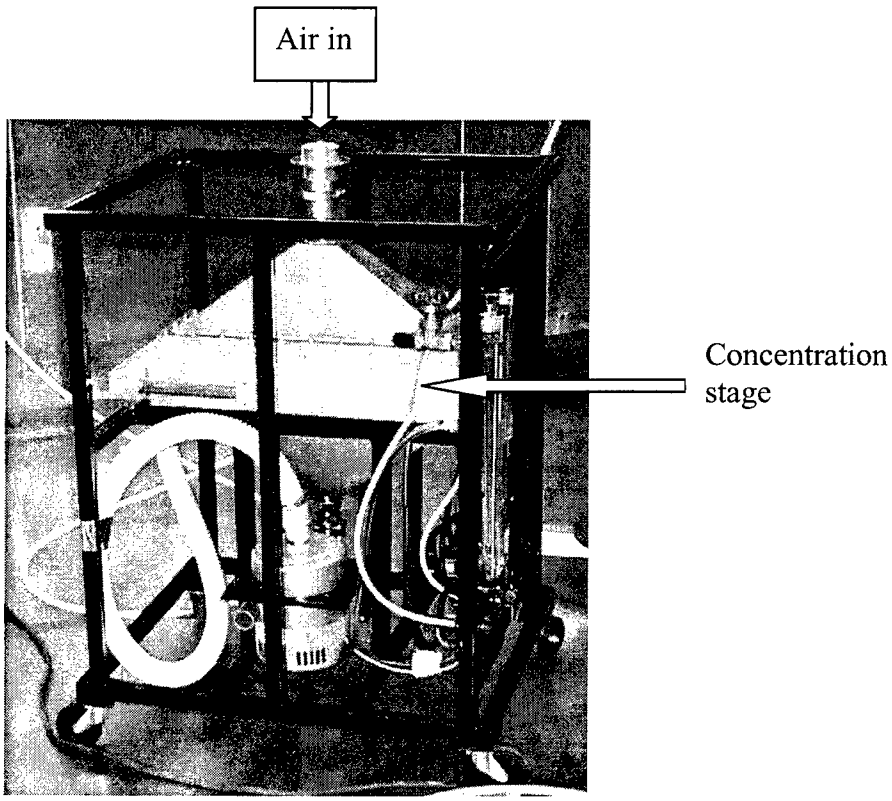

Figure 2. EULSI

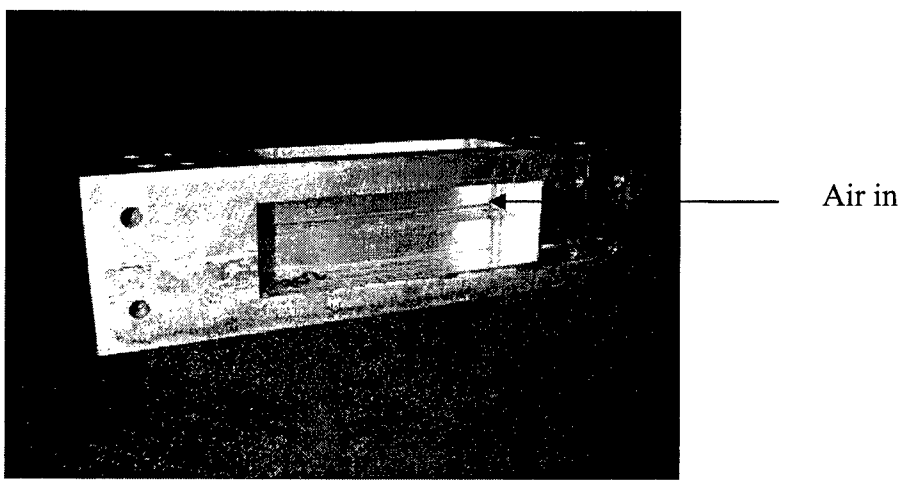

Figure 3. Individual EULSI Slot

Table 1. Characteristics of the EULSI

Number of Slots	8
Designed inlet air flowrate (L/min)	270
Measured air flowrate at the inlet (L/min) (measured at ECBC)	367.1 – PSL tests 370.2 – Oleic acid tests
Minor air flowrate (L/min) (measured at ECBC)	24.1 – PSL tests 27.2 – Oleic acid tests
Power (Watt) (measured at ECBC)	115.5
Weight	Very heavy – Mounted on wheels
Dimensions (in.)	Length = 26 Width = 22 Height = 36

3. TEST PROCEDURES AND ANALYSIS

3.1 Sampling Efficiency Measurements.

The sampling efficiency tests were conducted with three kinds of aerosols and corresponding analyses methods. The first method used monodisperse fluorescent PSL microspheres. The second method used monodisperse fluorescent oleic acid particles, and the third method used dry Bg aerosolized with a sonic nozzle. The sampler and corresponding reference filters sampled the air simultaneously for 10 min. The aerosol generation and analysis methods are described in detail in Sections 3.2, 3.3, and 3.4.

3.2 PSL Microsphere Tests.

Sampling efficiency tests were conducted with 1- and 3-μm fluorescent PSL microspheres (Duke Scientific Corp., Palo Alto, CA). The PSL aerosol was generated using a 24-jet Collison nebulizer, then passed through a radioactive isotope (Kr-85) neutralizer to reduce the charge on the particles. During the experiment, aerosol was generated for 10 min, and mixed for 1 min before sampling.

The samplers and the corresponding reference filters sampled the PSL aerosol simultaneously for the same amount of time. Polycarbonate membrane filters (Osmonics Inc., Minnetonka, MN) were used as reference filters to collect the fluorescent PSL microspheres. After sampling, the sample filter and reference filters were collected. The membrane filters were processed to remove microspheres from the filters and place them (microspheres) into liquid for fluorometer analysis. The removal procedure consists of placing the membrane filters into 20 mL of filtered deionized water, then hand shaking for 10 s followed by placing the test tubes in a holder attached to a vortexer for 30 min. The samples were removed from the vortexer every 10 min and were shaken by hand for 10 s.

3.3 Sodium Fluorescein Tagged Oleic Acid (Fluorescent Oleic Acid) Tests.

Sampling efficiency tests were also conducted with 5-, 7-, 9-, and 12-μm fluorescent oleic acid particles. The monodisperse fluorescent oleic acid particles were generated using a Vibrating Orifice Aerosol Generator (VOAG, TSI Inc., St. Paul, MN). As with the PSL tests, the generated aerosol was passed through a Kr-85 radioactive isotope charge neutralizer to reduce the charge on particles, and then delivered to the chamber. The sizes of the fluorescent oleic acid particles were determined by sampling the aerosol onto a microscope slide inserted into an impactor, and then measuring the droplet size with a microscope. The measured fluorescent oleic acid particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982).[1] At the end of aerosol generation, the aerosol in the chamber was mixed for 1 min before sampling. The sampler and the corresponding reference filters sampled the aerosol simultaneously for the same amount of time. The sampler collected the sample on a glass fiber filter (Pall Corp., Ann Arbor, MI). In addition, glass fiber filters were used as the reference filters to collect fluorescent oleic acid particles.

A microscopic picture of fluorescent oleic acid droplets on a slide is shown in Figure 4. The measured particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982).[1]

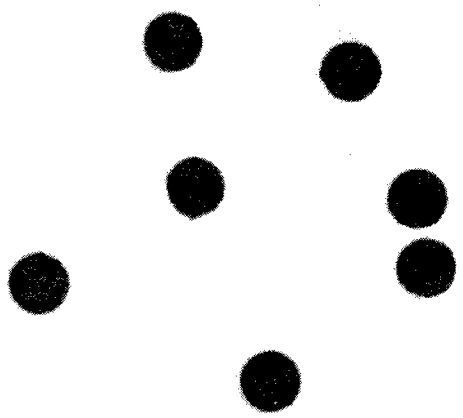

Figure 4. Microscopic Picture of Fluorescent Oleic Acid Droplets. Droplet size is approximately 10 μm.

Samples from the EULSI sampler were corrected for pH by adding NH_4OH before fluorometer measurements. Glass fiber filters were removed from filter holders, placed into a fluorescein recovery solution, and shaken on a table rotator (Lab-Line Instruments, Inc., Melrose Park, IL) for 1 hr. The recovery solution used in the tests had filtered deionized water with a pH between 8 and 10, obtained by adding a small amount of NH_4OH (e.g., 999 mL of water with 1 mL of 14.8 N NH_4OH). The fluorescence of the solution was measured using a fluorometer (Barnstead/Thermolyne, Dubuque, IA). All the samples were analyzed either the same day as the experiment or the next day. Factors that affect fluorescein analysis and the removal of fluorescein from filters are described in detatil by Kesavan et al. (2001).[2]

3.4 Bioaerosol Tests.

Various amounts (3 to 7 mg) of dry Bg [*Bacillus subtilis var niger* (*Bacillus globigii*)] particles were generated using the sonic nozzle. Similar to other methods, Bg was aerosolized, and the chamber air was mixed for 1 min to obtain a uniform aerosol concentration in the chamber. The reference filters and the sampler sampled the aerosol simultaneously for the same amount of time. At the end of sampling, the reference filters and the sample were collected for analysis. Glass fiber filters were used as the collection media in the sampler as well as in the reference filters.

3.5 Analysis.

Sampling efficiency was determined by comparing the amount of fluorescent material collected by the EULSI and the reference filters. The air flowrate of the sampler and the reference filters, and the liquid volume of the samples and reference solutions, were considered in the calculation.

The sampling efficiency was calculated using the following equation:

$$\text{Sampling Efficiency} = \frac{\left[\frac{(\text{fluorometer reading of sampler}) \times (\text{liquid volume})}{(\text{air flow rate})}\right]}{\left[\frac{(\text{fluorometer reading of reference filter}) \times (\text{liquid volume})}{(\text{air flow rate})}\right]} \times 100$$

4. RESULTS

The results are summarized in Table 2 and plotted in Figure 5.

Table 2. Sampling Efficiency of the EULSI for Various Particles Sizes

Particle Size (μm)	Particle Type	Sampling Efficiency (%)
1	PSL	21.1 ± 3.3
3	PSL	35.3 ± 4.8
5	Oil Drops	36.9 ± 2.0
7	Oil Drops	35.5 ± 1.3
9	Oil Drops	32.3 ± 0.5
12	Oil Drops	27.7 ± 1.2
0.9	Bg	16.7 ± 12.1

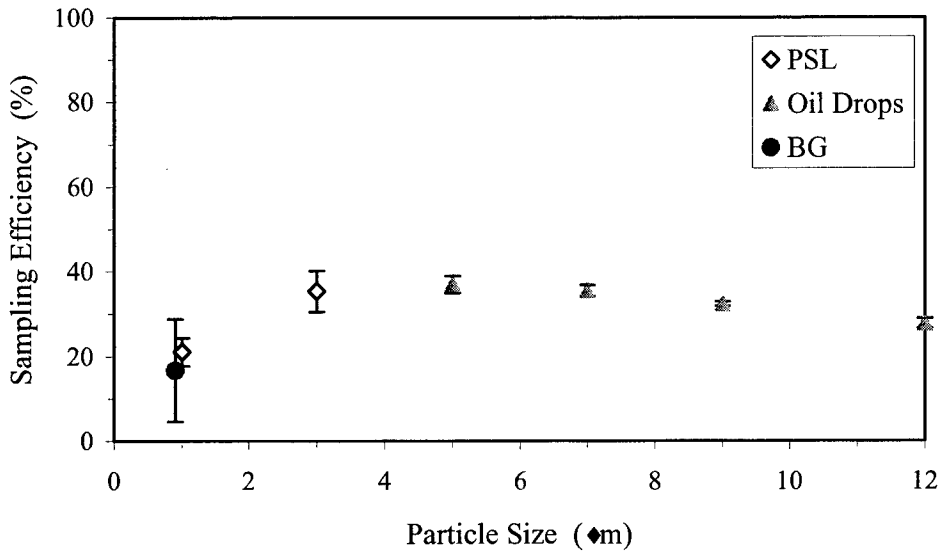

Figure 5. EULSI Sampling Efficiency

5. CONCLUSIONS

The aerosol sampling efficiency was determined for an Eight-Unit Linear Slot Impactor (EULSI) developed by Texas A&M University (College Station, TX). Sampling efficiency was determined using 1- and 3-μm fluorescent polystyrene latex (PSL) microspheres, 5-, 7-, 9-, and 12-μm fluorescent oleic acid particles, and dry Bg [*Bacillus subtilis var. niger* (*Bacillus globigii*)]. The results show a broad maximum sampling efficiency of 35 - 37% between 3 and 7 μm. The efficiency drops slightly to 28% at 12 μm.

The 1-μm PSL and single spore Bg particles yielded a similar sampling efficiency of 21.1% ± 3.3 and 16.7% ± 12.1, respectively. The higher standard deviation of Bg may be associated with the culturing analysis methods.

Information on sampling efficiency, size, weight, air flowrate, and power consumption of the sampler are given in the previous sections. The decision to consider a sampler for an application should include all these factors. Readers are advised that based on these test results, the sampler may be modified and improved as new technology becomes available. Therefore, a modified sampler may have very different characteristics than those discussed herein.

Future tests should evaluate the effect of high and low temperature, high humidity, and high dust concentrations on EULSI's sampling efficiency. High and low temperature may affect the slot width and the sampling efficiency. High humidity may allow water vapor to condensate on the inside of the sampler and remove particles from the air. Similarly, high dust concentrations may clog the narrow slots and affect the sampling efficiency. Currently, Texas A&M University is developing a circumferential slot impactor, and it is desirable to characterize this impactor and compare its results with those of the EULSI.

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